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PHYTOPLANKTON

Short research note

Structure of the diatom community of the River Adige (North-Eastern Italy) along a hydrological gradient

Barbara Centis · Monica Tolotti · Nico Salmaso

Abstract Physical constrains such as water discharge, suspended solids and turbidity act as dominant factors in driving the planktonic diatom assemblages of the River Adige (North-Eastern Italy). Two sampling stations, characterised by different hydromorphological features (Cortina all'Adige and Boara Pisani, with torrential and more potamal characteristics, respectively) were sampled fortnightly following an integrated approach encompassing physical, chemical and biological measurements and aiming at identifying the dominant factors controlling the temporal development of the community. A morpho-functional approach was used to classify the diatom assemblages where Morpho-Functional Diatom Groups (MFDG) were defined for diatom genera, according to their morphology, habitat selection and modality of adhesion to river substrate. In the two sampling points, algal growth was never limited by nutrients or zooplankton. The irregular development of MFDG was determined by the stochastic hydrological events and changes in variables related to water discharge (suspended solids and light attenuation). Tychoplanktonic, benthic and drifted taxa (such as *Diatoma* spp., *Encyonema* spp., *Navicula* spp. and *Nitzschia* spp.) were dominant in the torrential station (Cortina all'Adige), while the contribution of euplanktonic unicellular centric taxa (such as *Cyclotella* spp., and *Stephanodiscus* spp.) was higher in the potamal station (Boara Pisani).

Keywords Diatoms · River Adige · Physical forcing · Morpho-Functional Diatom Groups

Like every other potamoplanktonic organism, diatom dynamics in rivers are regulated by hydrological (e.g. water discharge, residence time and turbulence), physical (e.g. water temperature and turbidity), chemical (e.g. mineral content/conductivity and nutrient concentrations), and biological (grazing and competition) factors (e.g. Reynolds & Glaister, 1993; Basu & Pick, 1996, 1997). As environmental drivers co-act simultaneously, it is not easy to identify which has the most important impact on the river community. Some researchers have concluded that, due to the observed highly significant positive relationship between river phytoplankton abundance and total phosphorus concentration (e.g. Basu & Pick, 1996; Van Nieuwenhuyse & Jones, 1996; Borics et al., 2007), potamoplankton is regulated by nutrient concentrations while other studies indicated hydrology-related factors

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B. Centis (✉) · M. Tolotti · N. Salmaso
IASMA Research and Innovation Centre, Environment and Natural Resources Area, Fondazione Edmund Mach, Via E. Mach, 1, 38010 S. Michele all'Adige, Trento, Italy
e-mail: barbara.centis@iasma.it

as having greater importance to phytoplankton development in rivers (e.g. Reynolds et al., 1994; Pace et al., 1992). Nevertheless, such hydrological and physical constrains may well be overriding at certain times of the year, which include episodes of high discharge, when plankton is quickly transported seawards, embedded in a medium rendered so turbid by entrained fine particulate matter that net population increase is impossible owing to light deprivation (Reynolds, 2000). It is therefore little wonder that the relatively few types of planktonic organisms that are successful in rivers, as small centric diatoms, are characterised by clearly r-selective properties (i.e. high exploitative ability and opportunistic development; Reynolds, 2000). Ruse & Love (1997) have found a steady and prolonged decline of pennate diatoms with increasing discharge in the River Thames and a complete unimodal response to discharge for the centric filamentous diatom *Melosira varians*. Laboratory experiments with glass substrata also showed that small cells were dominant at all current velocities and no large taxa were dominant at any current velocity (Wendker, 1992). Experiments performed by Bormans & Condie (1998) indicated that physical and hydrological factors play a key role in the riverine ecosystem and that a proper knowledge of them is crucial for both sampling design and the interpretation of recorded algal densities.

The objective of this contribution is to assess the influence of the main physical and chemical factors on the planktonic diatom community at two stations of the River Adige (North-Eastern Italy), which are characterised by different hydromorphology and seasonal variability. Temporal changes in diatom species composition and relative abundances were assessed by applying multivariate statistical analyses on diatom groups defined on the basis of their morphological and functional characteristics. In fact, classifications based on functional and ecological characters have proven to be a powerful tool in community analysis in respect to previously applied taxonomic grouping (e.g. Reynolds et al., 2002; Salmaso & Padisák, 2007; Padisák et al., 2009).

River Adige is the second longest river in Italy (409 km). Its spring is located in the Eastern Alps, at 1,550 m a.s.l. and the mouth is on the Adriatic Sea. More than a half of the catchment area (12,100 km^2) is located in mountainous regions. The northern sampling station is Cortina all' Adige (further on Station 1) which is placed 125 km from the spring. It has torrential characteristics and the height of waters generally ranges between 1.5 and 3 m. The southern sampling station, Boara Pisani (Station 2, located 59 km to the mouth), has more potamal characteristics, with a water height generally ranging between 4.5 and 7 m.

Sampling was carried out in both stations every 15 days, twice a month, from March 2007 to February 2008. The water samples were collected from bridges, at midstream, using a bucket. Temperature was measured immediately after the sample withdrawal, like conductivity and pH. Chlorophyll-*a* concentration was determined spectrophotometrically on acetone extracts. Other determinations in laboratory included water turbidity (NTU, Nephelometric Turbidity Units), dry weight (suspended solids) and nutrients (SRP, Soluble Reactive Phosphorus; TP, Total Phosphorus; DIN, Dissolved Inorganic Nitrogen, NO_3–N + NO_2–N + NH_4–N; Si, Soluble Reactive Silica; A.P.H.A., A. W. W. A. & W. E. F. 1995). Discharges (D_{3d}) were calculated as the average values recorded during the 72 h before the sampling operations. Further details on field sampling, data collection and analytical procedures are reported in Salmaso & Zignin (this volume).

Water samples for diatom analyses were concentrated by sedimentation (1:50) and then cleaned in 30% hydrogen peroxide and 37% hydrochloric acid (Kelly et al., 1998). Cleaned diatom frustules were permanently mounted in Naphrax® resin. On each slide 400 valves were counted (European Committee for Standardization, 2004) under a light microscope at 1,000 magnification. Taxa were identified following the more recent monographs of the series Süßwasserflora von Mitteleuropa, established by A. Pascher (Gustav Fisher Verlag, and Elsevier, Spectrum Akademischer Verlag) and the most updated literature.

The ordination of diatom relative abundances was carried out by Non Metric Dimensional Scaling (NMDS) (Kruskal & Wish, 1978) applied to Bray and Curtis dissimilarity indices (Podani, 2000) computed on species percentages, after an arc-sinus transformation to reduce the weight of the most abundant taxa. The same normalisation procedure was also performed for Principal Components Analysis (PCA) on relative abundances of Morpho-Functional Diatom Groups. Statistical analyses were carried out with SYSTAT™ 10.2 and CANOCO™ 4.5 packages.

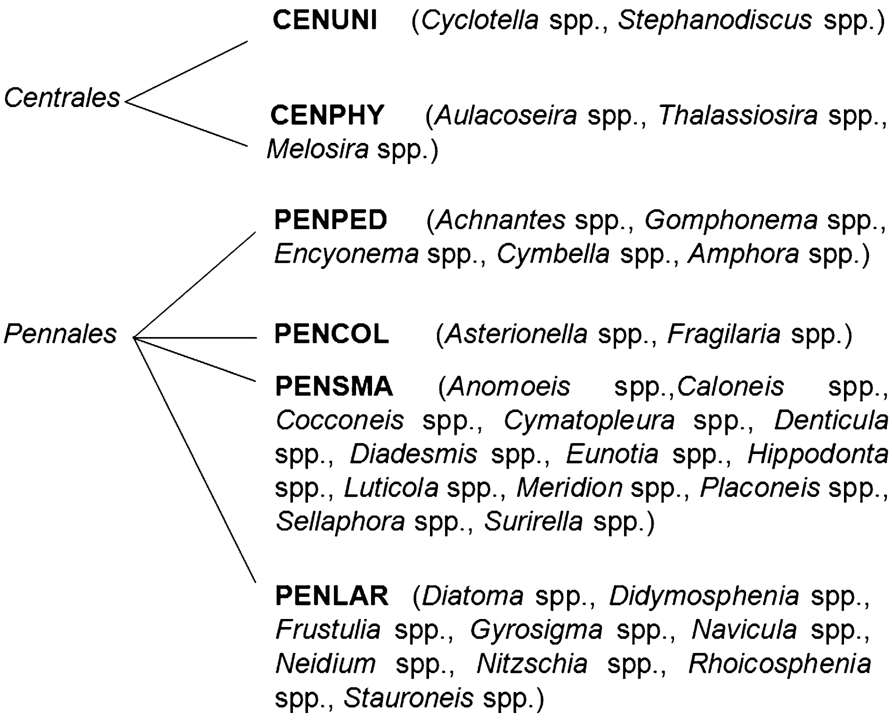

Fig. 1 Morpho-Functional Diatom Groups (MFDG). CENUNI (Centrales, unicells), CENPHY (Centrales, filaments), PENPED (Pennales with stalk), PENCOL (Pennales with colonial habits), PENSMA (Pennales smaller than 30 μm), PENLAR (Pennales larger than 30 μm

Seasonal diatom variations were analysed considering Morpho- Functional Diatom Groups (MFDG). The criteria adopted to discriminate the groups include morphology and, partly, habitat selection and modality of adhesion to river substrate (Fig. 1). The first division separates the two Bacillariophyceae orders (Centrales and Pennales). Within Centrales, the unicellular euplanktonic diatoms (CENUNI) are separated from the filamentous diatoms that can be planktonic or benthic, unattached to any substratum (namely the CENPHY) (Barber & Hawart, 1981). A similar splitting has been applied to the Pennales: PENPED comprehends taxa being attached with stalks better adapted to high-current velocities and displaying tychoplanktonic status (Sabater, 2009). PENCOL encompasses colonial diatom taxa. Further subdivisions were based on size ending in two heterogeneous groups mostly benthic or tychoplanktonic (Barber & Hawarth, 1981) (PENLAR and PENSMA).

Water discharge and turbidity in the two stations from March 2007 to February 2008 are reported in Fig. 2. In the northern station, monthly discharge values ranged between around 50 and 200 $m^3 s^{-1}$. Water turbidity generally varied between 4 and 34 NTU, with the exception of the peak occurred in early August of 318 NTU (Fig. 2a). The southern station showed higher discharge values (67–231 $m^3 s^{-1}$), while turbidity values were between 3 and 37 NTU, with the exception of a higher peak recorded in late June (Fig. 2b). Water temperatures ranged between 0.4 and 15°C in station 1 and between 2.8 and 22.4°C in station 2. Conductivity, suspended solids and pH ranged around 173–303 $\mu S\ cm^{-1}$, 3–43 $mg\ l^{-1}$ and 7.9–8.5 (Station 1), and 208–358 $\mu S\ cm^{-1}$, 2–44 $mg\ l^{-1}$ and 7.8–8.5 (Station 2).

DIN and silica showed similar concentrations in the two sampling stations, with values always higher than 0.5 $mg\ N\ l^{-1}$ and 1 $mg\ Si\ l^{-1}$. SRP showed higher values in the southern station (21–65 $\mu g\ l^{-1}$) than in the northern one (2–26 $\mu g\ l^{-1}$). In the latter station, SRP concentrations showed values below 5 $\mu g\ l^{-1}$ in the second half of June and between September and the first half of November. In both the stations, TP concentrations were always above 20 $\mu g\ l^{-1}$ (Salmaso & Zignin, this volume).

Chlorophyll *a* concentrations ranged between values below 0.5 and 5.7 $\mu g\ l^{-1}$ (Station 1) and 6.9 $\mu g\ l^{-1}$(Station 2). In the northern station, the dominant species were mostly represented by tychoplanktonic and drifted taxa such as *Diatoma vulgaris*

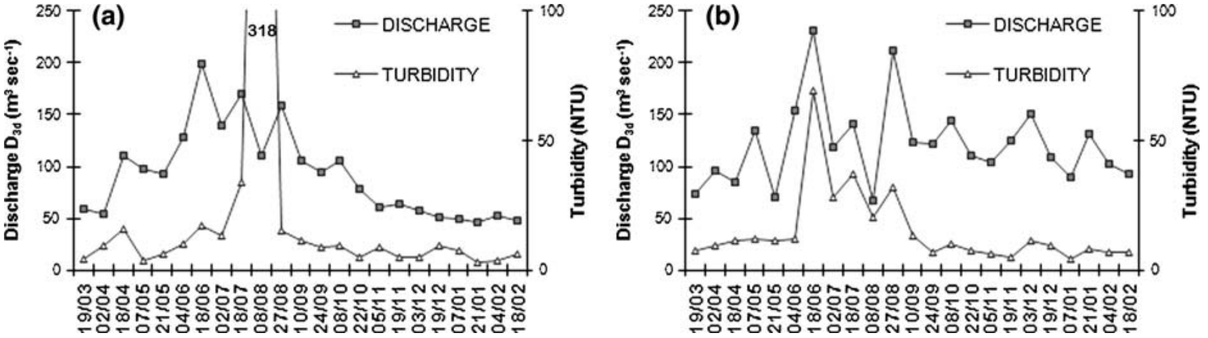

Fig. 2 Water discharge (D_{3d}) and turbidity (NTU) from March 2007 to February 2008 at **a** Cortina all'Adige and **b** Boara Pisani

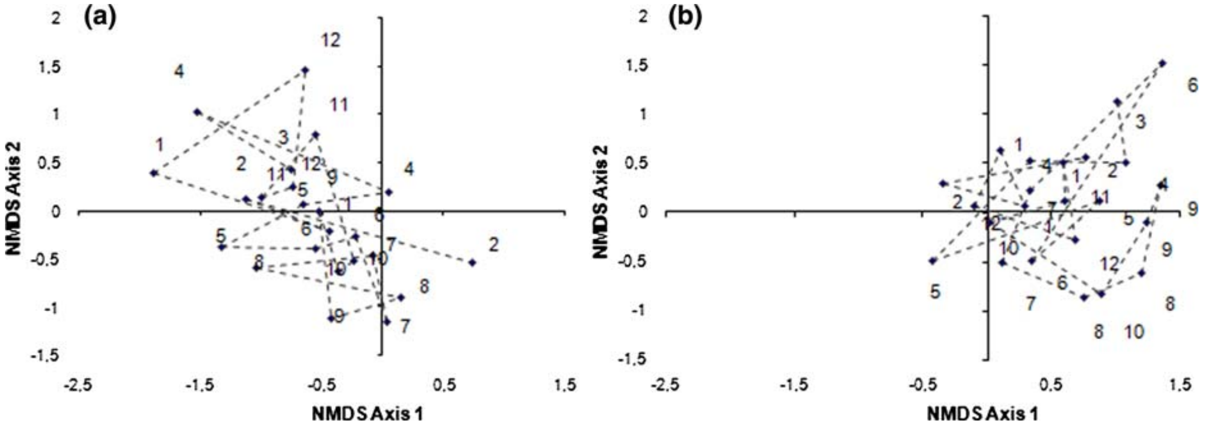

Fig. 3 Ordination of diatom samples by Nonmetric Multidimensional Scaling on Morpho-Functional Diatom Groups (MFDG); stress = 0.22. **a** Cortina all' Adige, **b** Boara Pisani; the Arabic numbers indicate the month of sampling, from March 2007 to February 2008

and *D. ehrenbergii*, *Encyonema silesiacum* and *E. minutum*, *Navicula lanceolata* and *N. tripunctata*. In the downstream station, there was a higher abundance of small centric taxa such as *Cyclotella meneghiniana*, *Stephanodiscus hantzschii*, *S. parvus* and *Melosira varians*.

The different structure of the diatom community is well reflected by the results of NMDS and PCA ordinations (Figs. 3, 4). The two NMDS configurations are the result of a single NMDS analysis but to avoid superimposition of different samples, the results are presented separately for each station. The chronological order of the diatom samples in the two stations followed different paths. Samples were characterised by pronounced, but not directional, seasonal development. Both the coordinates of the first and second axes of the NMDS configuration showed no significant correlations with the environmental variables ($P > 0.1$, $n = 46$). By converse, when considered separately, the configurations of the two stations showed clear and significant correlations with a few physical variables. The first axis of Station 1 was positively linked ($P < 0.05$, $n = 23$) with D_{3d}, dry weight and turbidity, while the second axis was negatively correlated with D_{3d} and turbidity. The correlation of the NMDS configuration with the physical variables in the Station 2 was apparent only along the second axis, which showed a negative and significant ($P < 0.05$, $n = 23$) relationship with D_{3d}, dry weight and turbidity.

The different biological characteristics of the two river stretches were further confirmed by the results of Principal Components Analysis (PCA) based on MFDG, which showed a stronger presence of tychoplanktonic, drifted and benthic taxa in the northern station and a higher abundance of euplanktonic taxa in the southern station. The hydrological regimes of the two stations seemed to play a crucial role in

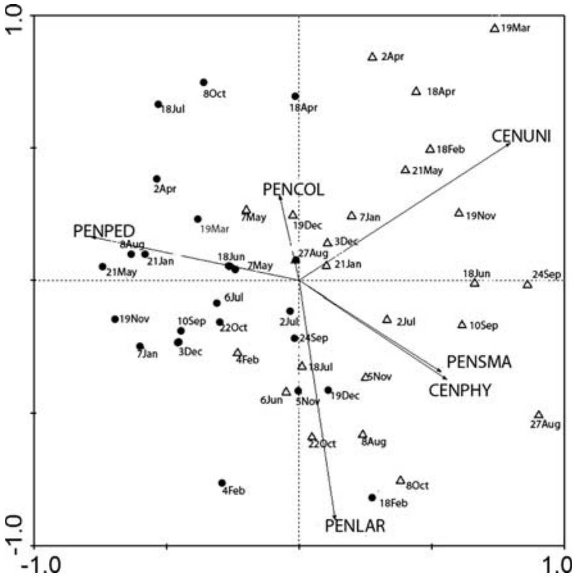

Fig. 4 PCA analysis on Morpho-Functional Diatom Groups (MFDG) for Cortina all'Adige (station 1—marked with *filled circle*) and Boara Pisani (station 2—marked with *open triangle*) from March 19 to February 18

selecting different functional groups. Torrential conditions in the northern station, consisting of relatively low water levels and higher water velocity, expose the river bed to a stronger erosion and scraping action by the waterflow so that planktonic diatom community in this site mainly included drifted or tychoplanktonic and meroplanktonic pennate taxa (as shown by PCA on Morpho-Functional Diatom Groups, Fig. 4). In the downstream station, on the opposite, the percentage of centric diatoms (C or CR strategist, sensu Reynolds, 2006) was higher (Fig. 4), in accordance with higher water levels and more pelagic conditions displayed by the station and consistent with the results provided by previous investigations (Salmaso & Braioni, 2008).

According to Roeder (1977), the statement that benthic diatom communities are the source of the riverine phytoplankton may be too simplistic. Reynolds & Glaister (1993) argued that the distinction between algae, which obligately grow on surfaces and those which lead a planktonic existence, is not so simple because some species are not necessarily restricted to either habitat. Typical examples may be represented by *Aulacoseira* and *Melosira* spp. that we have found in the samples. From the perspective of further development of the MFDG cluster (e.g. considering splitting based on pelagic and benthic life-styles; Fig. 1), more detailed information is needed on the autoecology of the single taxa. In this context, further research on River Adige will be aimed at studying the connection between the benthic and pelagic river habitats.

In the two sampling stations, algal growth was never limited by nutrients, the concentrations TP and DIN were always above limiting values (cf. Reynolds, 2006). Similarly, silica was always present with non-limiting concentrations. Considering a few cases of very low concentrations of available SRP, P deficiency for diatoms having higher P requirements (such as the small centric species, Wehr & Descy, 1998) could not be excluded in the northern station. However, taking also into account the low abundance of zooplankton in River Adige (Salmaso & Braioni, 2008), temporal diatom dynamics were strongly controlled by physical factors, mainly water discharge and the variables directly connected to hydrology (light absorption). These factors do not have a predictable temporal dynamics if compared to environmental factors acting cyclically on inertial systems less impacted by hydrological disturbances (e.g. large and deep lakes). This is reflected also on the irregular seasonal variability of diatoms and confirms the results presented in other studies (e.g. Dokulil, 1994), where combination of discharge, suspended particle concentration and temperature revealed to regulate algal growth rates and hence biomass levels.

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